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SUBSURFACE CAMBRO-ORDOVICIAN STRATIGRAPHY of NORTHWESTERN PENNSYLVANIA and BORDERING STATES

by

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ABSTRACT

An attempt is made to reconcile Cambro-Ordovician nomenclatural sequences converging on northwestern Pennsylvania from Ohio, New York, and central Pennsylvania. By means of well-sample studies, radioactivity logs, and pertinent literature the Cambro-Ordovician strata in subsurface of northwestern Pennsylvania are related to correlative outcrop areas in the Upper Mississippi Valley, in the region south and southwest of the Adirondacks in New York, and in the Nittany Arch area in central Pennsylvania.

Two widespread unconformities interrupt the Cambro-Ordovician succession, one occurring within the Beekmantown Group and the other located at the top of the Beekmantown.

The facies relationship between the Theresa and Little Falls formations in western New York is re-emphasized and the Utica Shale is considered to be a facies of the upper part of the "Trenton limestone" in northwestern Pennsylvania and Northern Ohio.

GENERAL REMARKS

The purpose of this paper is to relate the carbonate rocks of the Cambrian and Ordovician systems at outcrops in New York, central Pennsylvania, and the Upper Mississippi Valley with those located in the subsurface of western Pennsylvania and adjacent areas. The writer's knowledge of the rocks at outcrop is not from personal study, but has been gained from perusal of the literature, particularly the literature of the past fifteen years. Data from subsurface have been obtained chiefly from examination of drill cuttings from deep wells in northwestern Pennsylvania, from well-sample descriptions by the late C. R. Fettke, and from radioactivity logs. This paper is primarily a re-interpretation and summation of the existing data.

Plate 1 (in pocket) is a cross-section from Wood County, West Virginia to Chenango County, New York. It shows an interpretation of the stratigraphic relationship of the sediments in northwestern Pennsylvania with those in the general area of the Mohawk Valley, New York; it also shows how the Upper Mississippi Valley terminology may be applied to the region close to the Ohio-Pennsylvania border. Correlations have been based on lithology and gamma-ray characteristics. After rock correlations were established, both lithologic and published faunal correlations were referred to in order to assign recognized stratigraphic names to the subsurface rock units.

Figure 1 is a time-stratigraphic chart compiled from published literature with some modifications made in the New York column. The right side of the New York column represents the time-rock stratigraphy of the area south and southwest of the Adirondack Mountains and the left side is an interpretation of the stratigraphy of the K. R. Wilson #1 well in Wyoming County. By placing the stratigraphic units of the Wilson well in the table, an attempt is made to give time-stratigraphic significance to the subsurface rock units.

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UPPER CAMBRIAN STRATIGRAPHY

In Ohio, metasediments and granitic rocks underlie deposits of Late Cambrian age. In western Pennsylvania and western New York, so far as they are known, only the granite rocks are present. Though the igneous and metamorphic rocks are commonly regarded as "Precambrian basement" there is the possibility in Ohio that the metasediments (the carbonates and low grade schists) may be of Lower or Middle Cambrian age. Because of the meager information available, this paper follows the general practice of allocating to the Precambrian all metamorphic and igneous rocks located below the Upper Cambrian sandstones.

The Upper Cambrian sediments, where lying directly upon the "basement" in the Northern Appalachian Basin, grade upward from sandstone at the base to interbedded sandstones and sandy dolomites, which in turn pass upward into sandy and non-sandy dolomites. In the Michigan Basin and at outcrops in the Upper Mississippi Valley, rocks of Late Cambrian age are more quartz-bearing and have less carbonate content than those of comparable age in the Northern Appalachian Basin.

Upper Cambrian Nomenclature

The Upper Cambrian deposits of the Upper Mississippi Valley have been divided into three formations by Twenhofel, Raasch, and Thwates (1935). They are, in ascending order, the Dresbach Formation, the Franconia Formation, and the Trempealeau Formation; the first two named units are primarily sandstones and the last one is composed mainly of dolomite and sandstone. Cohee (1945a, 1948) has traced the formations from outcrop in southern Wisconsin into the subsurface of the Michigan Basin and adjoining areas of northern Indiana, northwestern Ohio, and southwestern Ontario. The formations have been identified east of the Findlay Arch in central and northeastern Ohio by Shearrow (1957, 1959a) and Fettke (1948), and in West Virginia by Shearrow (1959b) and Prouty et al (1959). The writer of this paper proposes that they can also be recognized in parts of western Pennsylvania.

In the Upper Mississippi Valley the lowermost Dresbach Formation is subdivided into three members: (Twenhofel et al, 1935) the basal Mount Simon Sandstone Member, the middle Eau Claire Member composed of glauconitic, dolomitic sandstone, and the upper Galesville Member formed of non-glauconitic sandstone. Traced from southern Wisconsin into Ohio and western Pennsylvania each member becomes deserving of formational status because each one retains sufficient identity over a considerable distance. Cohee (1948), Shearrow (1957, 1959b), and Fettke (1948) have ranked as formations the Mount Simon and the Eau Claire, but nomenclatural difficulties have plagued the term "Dresbach".

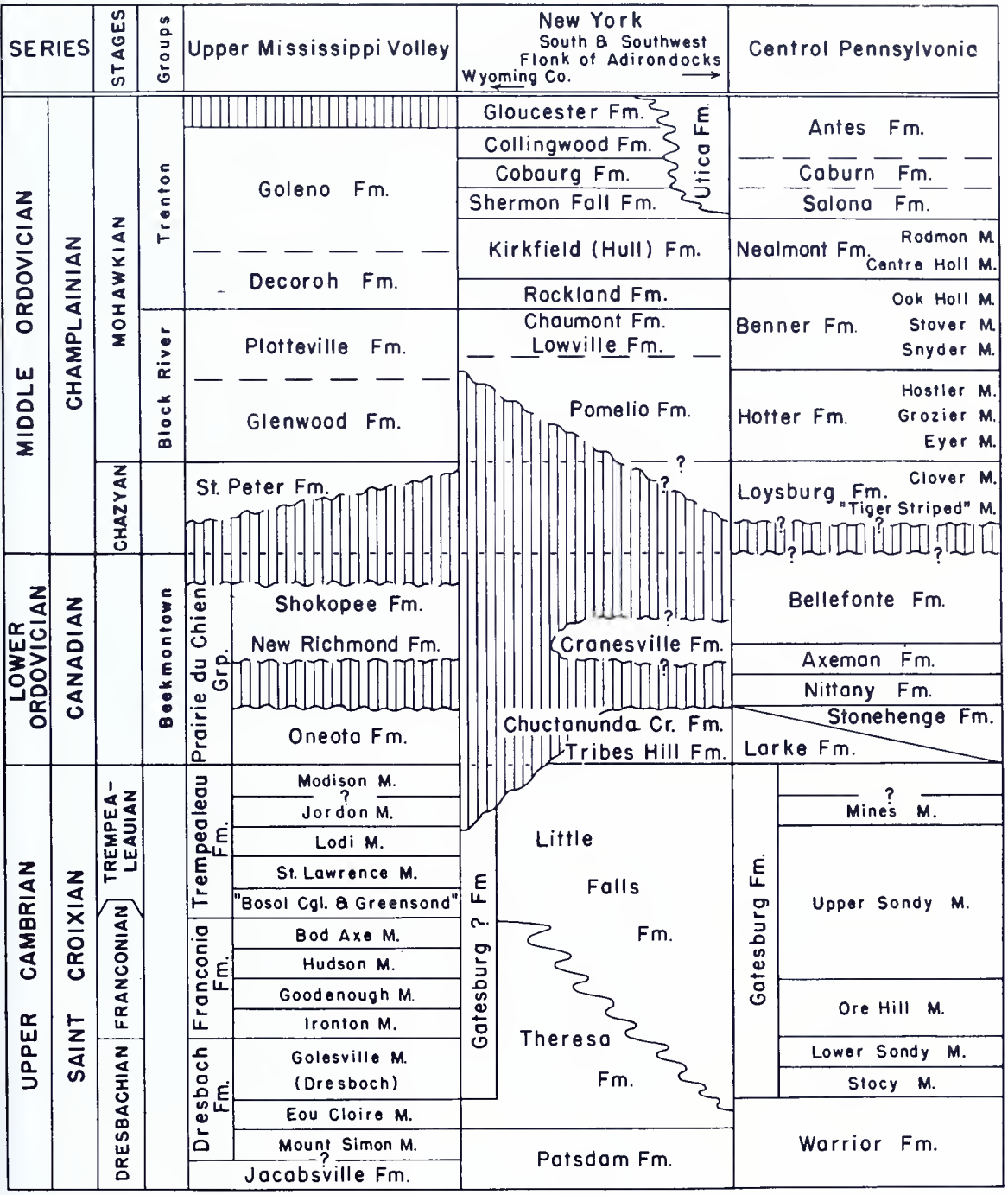

Fig. 1 **Time-Stratigrophic Correlotion Chort of Cambro-Ordovicion Corbonates in Upper Mississippi Volley, New York, and Central Pennsylvania**

Modified from Dapples (1955), Fisher (1954), Howell et al. (1944), Kay (1937, 1948), Neuman (1951), Ranes (1955), Sonda (1957), Stauffer and Thiel (1941), Twenhofel et al. (1935), Wilson (1952)

Dashed horizontal lines show indefinite boundaries; wavy lines indicate unconformoble boundaries. Closely spaced vertical lines indicate missing strata. Space apportioned to the units does not denote relative thickness.

As originally defined, the Dresbach included the Ironton Member of the Franconia Formation and extended downward to the top of the Eau Claire Formation (Wilmarth, 1938, p. 631). Today there are two meanings for the term, neither of which coincides with the original definition, for both exclude the basal Ironton Member of the Franconia. Cohee (1945a), Shearrow (1957, 1959b) and Fettke (1948) consider the Dresbach Formation to include all beds from the base of the Franconia to the top of the Eau Claire Formation. The second meaning is that proposed by Trowbridge and Atwater (1934) and defines the Dresbach Formation as extending from the base of the Franconia Formation to the base of the Mount Simon Member, thus including, as members, the basal Mount Simon, the middle Eau Claire, and the upper sandstone unit which has been renamed Galesville. The writer prefers the latter meaning for the following reasons:

1. In areas where the Eau Claire is a sandstone and cannot be differentiated from the overlying and underlying sandstones (Galesville and Mount Simon respectively), the term "Dresbach" has been applied to all the strata extending from the top of the Galesville to the base of the Mount Simon.

2. "Dresbachian" has become a standard stage term and in the Upper Mississippi Valley it is represented by the Galesville, Eau Claire, and Mount Simon members inclusive.

In this paper, dealing chiefly with the Northern Appalachian Basin, the Galesville, Eau Claire, and Mount Simon will be considered as formations because these units can be recognized over sufficient distance to warrant formational designation. As a consequence the Dresbach is raised to group rank.

Jacobsville, Mount Simon, and Potsdam Formations

The writer follows Fettke (1948) in correlating the Potsdam Formation in New York with the Mount Simon and Jacobsville formations in Ohio and the Upper Mississippi Valley. Bordering the Adirondack Mountains in New York, the Potsdam, at outcrop, varies in thickness from zero on the western flank to approximately 1200 to 1500 feet on the northeastern flank (Swartz, 1948, p. 1538). The upper part is composed of white, quartz sandstone and quartzite, and the lower portion is red and arkosic, and contains fragments and pebbles of quartz and granite; the latter lithology, comprising much of the formation on the northeastern flank, thins to extinction to the south and west and is overlapped by the upper unit of white sandstone (Swartz, 1948, p. 1537-38). In the Lobdell well, south of the Adirondacks in Chenango County, New York (Plate 1, well No. 7), the lower red portion of the Potsdam is absent and the upper white sandstones, approximately 70 feet thick, rest upon the Precambrian.

In western New York however, red, arkosic sandstones are found between the Precambrian and the upper white sandstone unit. The K.R.Wilson #1 well, near the town of Arcade in Wyoming County (Plate 1, well No. 5), penetrated 165 feet of light-brownish-gray, very fine- to fine-grained

sandstone and an underlying 11 feet of pink arkosic sandstone (Fettke, 1948, p. 1471). Similarly, a recently completed well (Robert Olin #1, Woodhull Township, Steuben County) stopped after drilling through 106 feet of white to pale-green quartz sandstone and quartzite and 198 feet of red, arkosic and conglomeratic sandstone[1]. Both wells bottomed in the red sandstone and both are commonly thought to have stopped drilling not far above the Precambrian contact.

Overlying the Precambrian in northwestern Ohio and southeastern Michigan, there occurs a sequence lithologically comparable with the Potsdam Formation of New York. The lower red, arkosic sandstones, tentatively correlated with the Jacobsville Formation of the Northern Peninsula of Michigan (Cohee, 1945a) are here correlated with the red portion of the Potsdam; the upper unit called the Mount Simon Formation composed of non-fossiliferous, fine- to coarse-grained quartz sandstones (Cohee, 1945a) is equated with the upper sandstone unit of the Potsdam. The Mount Simon Formation ranges irregularly in thickness from 100 to 450 feet in Ohio (Shearrow, 1959a) to 2500 feet in northeastern Illinois (Cohee, 1948).

Eau Claire Formation

Whereas the Mount Simon and its correlative portion of the Potsdam Formation maintain a constant lithology from New York to the Upper Mississippi Valley, the Eau Claire Formation exhibits significant changes. In the Power Oil Co. Well #9634 in West Virginia (Bayles et al, 1956) (Plate 1, well No. 1) and the Emma McKnight well #1 in western Pennsylvania (Wagner, 1958) (Plate 1, well No. 2), the latter of which penetrated the upper 55 feet of the Eau Claire, the formation is composed of medium- to dark- colored, argillaceous dolomite, in part oolitic and in part shaly. North and northwestward from the tri-state region of northern West Virginia, southeastern Ohio, and southwestern Pennsylvania, the Eau Claire Formation becomes increasingly quartz-sandy. In northwestern Ohio and southeastern Michigan (Cohee, 1945a), and in southwestern Ontario[2], it is a sandy dolomite with interbedded sandstones, and it becomes entirely sandstone in Michigan's Northern Peninsula (Cohee, 1948), and in outcrops in southeastern Wisconsin (Twenhofel et al, 1935).

In Ohio the Eau Claire Formation varies from 400 to 700 feet in thickness (Shearrow, 1959a); and in southeastern Michigan (Cohee, 1948) and southwestern Ontario it ranges from 250 to 300 feet.

1.) Unpublished skeletal sample log from New York State Natural Gas Corp., Pittsburgh, Pa.

2.) Unpublished core description of U. S. Steel Diamond Drill Hole #1, Charlottesville Twp., Norfolk County, Ontario by B. V. Sanford, Canada Geological Survey.

The Eau Claire, where present as a dolomite, is easily distinguished from the enclosing sandstones of the Mount Simon and Galesville formations. It is characterized by being more argillaceous, less sandy, and occasionally carrying dark-colored dolomitic oolites. In areas where the Eau Claire is a sandstone the most valuable criterion for differentiation is the presence of glauconite which is not found in either of the adjacent formations.

The Eau Claire Formation correlates with the lower part of the Theresa Formation of New York. In central Pennsylvania the Warrior Formation is correlated with the interval extending from the top of the Eau Claire to the base of the Mount Simon, or perhaps the base of the Jacobsville Formation.

Franconia-Galesville and Theresa Formations

West of the Findlay Arch and in the Upper Mississippi Valley the sandstones of the Galesville Formation are differentiated from the enclosing sandstones by the absence of glauconite. East of the arch, however, glauconite is absent not only from the Galesville, but often is missing from both the overlying and underlying Franconia and Eau Claire formations. Consequently, stratigraphic distinction based solely on the presence of glauconite cannot always be made. Thus Shearrow (1957), in Ohio, combines under the name "Franconia-Dresbach" the sandy interval between the dolomites of the Eau Claire and Trempealeau formations. The writer follows Shearrow's example but prefers the name "Franconia-Galesville" for reasons previously given.

The Franconia-Galesville formations are composed of a light-colored, very fine- to coarse-grained, dolomitic sandstone ranging from 75 to 125 feet thick in Ohio (Shearrow, 1957, 1959a; Fettke, 1948), southeastern Michigan (Cohee, 1945a, 1948), and western Pennsylvania (Wagner, 1958). From northeastern Ohio and northwestern Pennsylvania into northerr West Virginia the interval increases in thickness. In the Power Oil Co. well #9634 the Franconia-Galesville formations are 210 feet thick and the sandstone in the upper part of the section has been replaced by sandy dolomite. In the Nittany Arch region of central Pennsylvania the Franconia-Galesville time-stratigraphic interval reaches a minimum thickness of 800 feet and a possible maximum of 1000 to 1200 feet. The interval, in that area of Pennsylvania (Wilson, 1952), is represented by the lower part of the Gatesburg Formation, which is more specifically identified (in descending order) as the lower part of the Upper Sandy Member, the Ore Hill, Lower Sandy, and Stacy members.

The Franconia-Galesville and Eau Claire formations of Ohio and western Pennsylvania are correlated with the Theresa Formation of New York. The Theresa is a transitional unit of sandy dolomites and interbedded sandstones lying above the clear, quartzose sandstones of the Potsdam Formation and below the slightly sandy dolomites of the Little Falls Formation. In the Mohawk Valley, south of the Adirondack Mountains, the Theresa is 50 to 150 feet thick (Swartz, 1948), and in subsurface the formation reaches a thickness of approximately 1450 feet in the Robert Olin #1 well in Steuben County.

Considerable disagreement has arisen over the placement of the Upper boundary of the Theresa Formation in subsurface. The Upper Cambrian section of the C. C. Lobdell #1 well in Chenango County, New York (less than 40 miles from Theresa outcrops in the Mohawk Valley) represents an extreme example of the diversity of opinion on where the top of the Theresa is to be established. In this well 781 feet of sandy dolomites separate the points which several authors (Donnerstag, 1950) choose as the upper contact.

A facies relationship between the Little Falls and Theresa formations is offered to explain why, in subsurface, there is little agreement on the top boundary of the Theresa. Cushing in 1916 (p. 28 and 35) suspected such a relationship when he stated that lithologically the sandstone beds in the Ogdensburg vicinity are much like the underlying typical Theresa although they occupy time interval of Little Falls dolomite in the Mohawk Valley. As the interval between the top of the Cambrian and the top of the Potsdam is traced westward from the Lobdell well, sandstones begin to appear in the section and also increase in thickness and in the Wilson #1 well in western New York almost one third of the Little Falls- Theresa interval is composed of quartzose sandstone.

It is suggested that the top of the Theresa Formation in the Lobdell well be placed at the top of the first sandstone at 5137 feet or perhaps more accurately at 4971 feet where correlations by both gamma ray logs and lithology indicate that the top of the Theresa Formation is lithologically equivalent with the top of the Franconia-Galesville Formations in western Pennsylvania and eastern Ohio. This latter lithologic equivalence is in agreement with published faunal correlations (Wilson, 1952, pl. 4).

Trempealeau, Little Falls, and Gatesburg Formations

The Trempealeau Formation of southern Wisconsin is 60 to 175 feet thick and is divided into five members (Twenhofel et al, 1935) which, in ascending order, are named the "Basal Conglomerate and Greensand Member", the St. Lawrence Member, the Lodi Member, the Jordan Member, and the Madison Member. In subsurface, Cohee (1945a) has tentatively traced the middle three members around the margin of the Michigan Basin. The lowest member is generally only a few inches thick and was probably incorporated by Cohee into the base of the St. Lawrence Member. In the Colvin-Voss #1 well in southeastern Michigan Cohee (1945a) assigned over 500 feet to the Trempealeau Formation, of which the lower 150 feet was allocated to the St. Lawrence Member and the upper 350 feet to the Lodi Member. The overlying Jordan and Madison Sandstone members, as well as most of the Lower Ordovician strata, are missing. The St. Lawrence Member in the Colvin-Voss well consists of a basal sandy dolomite overlain by black dolomite shale and shaly dolomite; the Lodi Member is a light colored, partially sandy, dolomite.

As in southeastern Michigan, the upper portion, and occasionally all, of the Trempealeau is missing in northern Ohio. It is only in the southern part of Ohio and Pennsylvania that the total section of the Trempealeau Formation can be found. In the Power Oil Co. well #9634 the interval

of 949 feet (11,287 to 12,236) assigned to the Trempealeau is divided into three units of dolomite: a lower argillaceous to non-argillaceous unit, a middle silty to sandy unit, and an upper cherty unit. The lower unit, 313 feet thick (11,923-12,236), is tentatively correlated with the St. Lawrence Member and consists of pure dolomite overlain by dark argillaceous dolomite. This unit can be distinguished in the McKnight #1 well (7940 to 8050), but becomes less apparent in the Shaw #1 well (9225? to 9348), and it cannot be recognized in wells in western New York.

The middle unit in the Power Oil Co. well #9634, 434 feet thick (11,489? to 11,923), is composed of light-to medium-colored, partially silty and sandy dolomites. The interval is believed to be lithologically equivalent to the Lodi Member, as that member is defined by Cohee (1945a) in the Colvin-Voss #1 well in southeastern Michigan. Approximately 150 feet below the top of the Lodi Member in the Power Oil Co. well is a 100 foot sequence of sandstone that can be followed from West Virginia to western New York where it is a sandstone unit within the Little Falls or Gatesburg Formation. The top of this sandstone has also been considered by some geologists (Fettke, 1948) to be the top of the Theresa Formation. Because of the continuity of this sandstone throughout western Pennsylvania and southwestern New York, its absence from the Shaw well is noteworthy.

In the Power Oil Co. well #9634 the upper unit of the Trempealeau Formation is a cherty and somewhat sandy dolomite, with thin interbeds of sandstone at the top. Occasional oolites of chert are present. The unit is approximately 200 feet thick (11,287 to 11,489). On the basis of lithology and stratigraphic position, this unit is related to both the Jordan Sandstone Member in the Upper Mississippi Valley and to the Mines Member of the Gatesburg Formation in central Pennsylvania - the sandiness being related to the Jordan and the chert and siliceous oolites being reminiscent of the Mines. It might seem logical, by reason of geographical proximity, that Upper Cambrian sediments in western Pennsylvania should be more closely related lithologically to the outcrop in the central part of that state than to the exposures in the Upper Mississippi Valley. Such, however, does not appear to be the case. Most of the Upper Cambrian deposits in western Pennsylvania and adjoining parts of West Virginia and Ohio can more easily be given Upper Mississippi Valley, rather than Appalachian, nomenclature. The source of the detrital sediments was located north and northwest of the area covered by the cross-section, and genetic relationships between the sediments in the Upper Mississippi Valley and western Pennsylvania are not as abstruse as might first be suspected.

The Trempealeau Formation is correlated with the Little Falls Formation of New York, the latter being a slightly sandy and silty dolomite with subordinate chert. Westward from outcrops in the Mohawk Valley to the subsurface in the K. R. Wilson well, the dolomites of the Little Falls Formation become more quartz-sandy and develop sandy intervals, one of which can be traced into the sandstone unit of the Lodi Member in western Pennsylvania and southeastern Ohio.

In the K. R. Wilson well in New York, the writer is undecided as to what nomenclature should be assigned to the upper part of the Upper Cambrian strata. The interval from the top of the Cambrian to the top

of the dolomite within the Theresa Formation is much too sandy to warrant the names "Trempealeau" or "Little Falls". Perhaps "Gatesburg" is a better name because the interval under discussion lies stratigraphically in the position of the Upper and Lower Sandy Members of the Gatesburg Formation in central Pennsylvania. And the lithology of this interval is somewhat, though not closely, similar to that of the Gatesburg.

CAMBRO-ORDOVICIAN BOUNDARY

An unconformity separating the Cambrian from the Ordovician has long been recognized, both in New York (Ulrich and Cushing, 1910, p. 97-99) and in the Upper Mississippi Valley (Twenhofel et al, 1935; Stauffer and Thiel, 1941, p. 50-55). The writer is inclined to minimize its regional importance and to restrict it to areas of local uplift or non-deposition. In the Lobdell well, Chenango Co., New York, for example, uplift occurring at the end of the Upper Cambrian along the trend of the Adirondack Axis permitted erosion of the upper part of the Little Falls Formation. In the Mohawk Valley, however, an unconformity at the systemic boundary is questionable (Fisher, 1954).

At outcrops in the Upper Mississippi Valley the Cambro-Ordovician unconformity is reported by Twenhofel and others (1935) to be indicated by a basal conglomerate and profound changes in both lithology and fauna. Eastward into the Appalachian Basin, however, it is the opinion of the writer of this paper that the unconformity may disappear. Reasons for minimizing the significance of an abrupt break in the stratigraphic record at the Cambro-Ordovician boundary are as follows:

1. Faunally, there is little need for a widespread or a major unconformity. In central Pennsylvania the Mines Member of the Gatesburg Formation may be uppermost Cambrian in age according to Wilson (1952). Howell (1944) correlates the Mines with the Saukiella-Calvinella zone of the Jordan Sandstone Member in the Upper Mississippi Valley. The Stonehenge Formation, overlying the Mines Member in central Pennsylvania, is correlated faunally with the Oneota Formation of the Upper Mississippi Valley and with the Tribes Hill Formation of New York. The Oneota, Tribes Hill, and Stonehenge formations are all of Gasconade (lowermost Ordovician) age. After faunal correlations are made, the only strata left unaccounted for are the sandstones of the Madison Member which lie between the Jordan Member and the Oneota Formation, and these sandstones have been considered to be in facies relationship with with the Jordan (Twenhofel et al, 1935).

2. In the area covered by the cross-section where Lower Ordovician strata have not been eroded away, the Cambro-Ordovician contact appears to be transitional.

LOWER ORDOVICIAN STRATIGRAPHY

The Lower Ordovician (Canadian) strata in this paper are divided into two units: the lower Beekmantown and upper Beekmantown. Differentiation between the two is based on lithology and the recognition of an unconformity. The writer, while realizing that these terms possess no formal definition, employs them merely as a convenience, because to his knowledge there is no one rock term lower than group rank (Beekmantown) which is applicable throughout the region from New York and central Pennsylvania to the Upper Mississippi Valley.

The lower Beekmantown consists of the siliceous dolomites of the Oneota Formation in the Upper Mississippi Valley, the Larke-Stonehenge formations in central Pennsylvania, and the Tribes Hill and Chuctanunda Creek formations in the Mohawk Valley, New York. The lower Beekmantown sequence, in the area of the cross-section, is more closely related lithologically to the Upper Cambrian than to younger Ordovician strata.

The upper Beekmantown unit includes a mixture of lithologies - dolomites, limestones, sandstones, siltstones and shales - which has been referred to in Ohio as the "Glenwood-St. Peter" interval, and in western Pennsylvania and western New York it has been inaccurately regarded as the lowest part of the "Trenton limestone".

The rock units comprising the upper Beekmantown are the New Richmond and Shakopee formations in the Upper Mississippi Valley, the Axeman and Bellefonte formations in central Pennsylvania, and the Cranesville Formation in the Mohawk Valley.

The datum line of the cross-section represents an unconformity that separates the lower Beekmantown from the upper Beekmantown in the Kesselring #1 well, Chemung County, New York and in the tri-state area of southwestern Pennsylvania, southeastern Ohio, and northern West Virginia. It is an unconformity of notable magnitude, successively truncating increasingly older strata as it is traced northward from the tri-state area into western New York and Ontario. North of Lake Ontario and a short distance north of Lake Erie, rocks of Middle Ordovician age rest upon the Precambrian, the whole of the Upper Cambrian and Lower Ordovician strata being missing. In central Pennsylvania the unconformity probably does not exist, suggesting that continual, if not continuous, deposition took place throughout Late Cambrian and Early Ordovician time.

Lower Beekmantown

The Oneota Formation in southwestern Michigan (Cohee, 1954a) and in the Illinois Basin (Atherton et al, 1954) is a light-colored, cherty, crystalline dolomite with some oolitic chert. In the Power Oil Co. well #9634 in West Virginia the writer has identified the dolomitic interval from 10,707 feet to 11,287 feet as the Oneota Formation because of the presence of chert, especially oolitic chert.

In central Pennsylvania the lower Beekmantown is represented by the Larke and Stonehenge formations which, according to Prouty (1954) are time-equivalent. The Stonehenge Formation is a fairly pure, finely-crystalline limestone with subordinate dolomitic limestone and edgewise limestone conglomerates at many horizons (Swartz, 1948). It is not present in western Pennsylvania and adjacent areas. The Larke Formation is composed of dark-colored, coarsely-crystalline dolomite containing very little sandstone and chert (Butts, 1945, p. 3). The only place in the cross-section to which the name "Larke" can be assigned is the interval allocated to the Oneota Formation in the Power Oil Co. well. The abundant quantity of chert in that part of the well section, however, is the reason for preferring the name "Oneota".

The lower Beekmantown of the Mohawk Valley, New York has been divided into two units: the Tribes Hill Formation at the base and Chuctanunda Creek Formation at the top, both are of Lower Canadian age (Fisher, 1954). According to Fisher (1954), the Tribes Hill Formation (approximately 145 feet thick) is composed of dense to finely-crystalline limestone, dolomite, and dolomitic limestone, which is partially silty and sandy, particularly at the base and top; numerous shale intercalations occur in the middle part of the formation. The Chuctanunda Creek Formation which overlies the Tribes Hill, is a dolomite; the upper half is cherty and contains much interstitial silica. In the Mohawk Valley area the formation is 40 feet thick and its upper boundary is unconformable with the overlying strata wherever that contact has been observed (Fisher, 1954).

The datum unconformity in the Lobdell and Kesselring wells is believed by the writer to lie at the top of the Chuctanunda Creek Formation, and the underlying 40 to 50 feet of cherty dolomite and dolomitic limestone has been assigned to that formation. Directly beneath the Chuctanunda Creek, the very finely-crystalline, silty and magnesian limestones from 4594 to 4795 feet in the Lobdell well, and the argillaceous and silty, very finely-crystalline dolomites from 9908 to 10,175? feet in the Kesselring well represent the Tribes Hill Formation.

Upper Beekmantown

The upper Beekmantown strata in the Upper Mississippi Valley are divided into the New Richmond Formation and the overlying Shakopee Formation. The New Richmond is a thin sandstone 5 to 20 feet thick in Wisconsin, northern Illinois, southwestern Michigan and northeastern Indiana (Cohee, 1945a). In the Illinois Basin it is reported to be between 100 and 190 feet thick, with interbeds of sandy dolomite (Atherton et al, 1954). The Shakopee Formation in the Upper Mississippi Valley is a light-colored dolomite and dolomitic limestone containing chert that is in part oolitic (Atherton et al, 1954; Willman and Payne, 1943); toward its base the formation becomes sandy and grades into the New Richmond (Stauffer and Thiel, 1941, p. 63). Because the Shakopee is lithologically similar to the Oneota Formation, differentiation between them in subsurface is very difficult, especially in areas where the New Richmond cannot be identified. Consequently the whole Lower Ordovician sequence of cherty dolomite is sometimes lumped together as the Prairie du Chien Group.

In southwestern Michigan, however, the Shakopee Formation changes from its Upper Mississippi Valley aspect to a shaly dolomite which may be in part sandy and cherty (Cohee, 1945a). The writer suggests that in the Power Oil Co. well in West Virginia the 218 feet of dark- to medium-colored, argillaceous, very fine-textured dolomite from 10,469 to 10,687 feet correlates with the Shakopee Formation although the interval appears to bear closer lithologic affinities with the Bellefonte Formation in central Pennsylvania.

The 20 feet of sandstone lying between the Shakopee Formation and the datum unconformity in the Power Oil Co. well is reservedly designated "New Richmond", but the name "Bellefonte sandstone" of the Bellefonte Formation may be a better designation.

Dolomite of dense to sublithographic texture is rare in the subsurface Cambro-Ordovician rocks of western Pennsylvania. But in the central Pennsylvania outcrop belt such dolomites form the upper part of the Bellefonte Formation and are excellently exposed along Tea Creek in the Kishacoquillas Valley (Swartz et al, 1955). Below or at the base of this dense dolomite is 0 to 20 feet of well-rounded, quartzose sandstone that has been informally called the Bellefonte sandstone; this is reported to be the only sandstone in the 4000 feet of Beekmantown strata in central Pennsylvania. The bottom 20 feet (7470-7490) of a core taken from the McKnight #1 well, Mercer County, Pennsylvania, is composed of dark-colored, very fine-textured to dense dolomite with interbeds of dolomitic shale and interbeds of very thinly- to thinly-laminated brown dolomite (Wagner, 1958). Fifty feet beneath the top of the dolomite (or 30 feet below the bottom of the core) is a 10-foot interval of well-rounded, very fine- to coarse-grained, dolomitic, quartz sandstone. The striking similarity of this section in the McKnight well with that of the dense dolomite and underlying sandstone of the Bellefonte Formation in central Pennsylvania is the main reason for assigning to the upper Beekmantown the 60 feet of strata above the datum unconformity in the McKnight well.

As mentioned above, the 218 feet of upper Beekmantown rocks above the datum unconformity in the Power Oil Co. well also resemble the central Pennsylvania Bellefonte Formation. The names Shakopee and New Richmond are used in the cross-section chiefly to suggest correlative relationships with the Upper Mississippi Valley stratigraphy.

In the Mohawk Valley of New York the Cranesville Formation is tentatively considered by Fisher (1954) to be of Upper Canadian age. It has a maximum thickness of 70 feet and consists of dolomite, in part silty and sandy, and dolomitic siltstone. At the base of the formation is a feldspathic sandstone. The Cranesville Formation in the Kesselring well is assigned a thickness of approximately 60 feet from 9805? to 9868 and is composed of light-colored, very finely-crystalline, silty, and dolomitic limestone underlain by poorly sorted and subangular to rounded quartzose sandstone.

Lower Ordovician Unconformities

Two major unconformities are associated with the Lower Ordovician strata, the datum unconformity and an unconformity at the top of the Lower Ordovician.

The datum unconformity is present in both the Upper Mississippi Valley and New York. In southeastern Minnesota a faunal hiatus is recognized at the contact of the Oneota and New Richmond formations (Stauffer & Thiel, 1941, p. 53), and the same contact in Crawford County, southern Wisconsin is one of angular-discordance (Andrews, 1955). Traced into New York the same unconformity is found between the Chuctanunda Creek and Cranesville formations. According to Fisher (1954), uplift in post-Early Canadian time caused withdrawal of the seas from the region of the Mohawk Valley.

In north-central and northeastern Ohio and northwesternmost Pennsylvania the unconformity possesses a magnitude greater than in the areas of outcrop (the magnitude being proportional to the thickness of the missing strata). After deposition of the Oneota Formation, uplift in this area permitted removal by erosion of all the lower Beekmantown strata and much, if not all in some localities, of the Upper Cambrian Trempealeau Formation. From northwestern Pennsylvania and adjacent areas basinward to the west, south, and east the unconformity becomes less significant until in central Pennsylvania it apparently disappears.

The unconformity at the top of the Lower Ordovician is also present over a widespread region. In the Upper Mississippi Valley the contact between the Shakopee and St. Peter formations is an unconformable one, much of the upper part of the Shakopee having been eroded off before deposition of the St. Peter (Stauffer and Thiel, 1941, p. 64-65). Eastward into western New York this unconformity merges with the datum unconformity where Middle Ordovician rocks overlie Little Falls or older Upper Cambrian formations. Northward into Ontario Precambrian rocks are found beneath those of Middle Ordovician age.

In the Mohawk Valley, New York, Fisher (1954), reports that uplift and folding of the Lower Ordovician rocks occurred subsequent to deposition of the Cranesville sediments. He states that Lowville strata of Middle Ordovician age rest upon the truncated folds of the Lower Ordovician rocks.

In central Pennsylvania a disconformity has been reported between the Upper Canadian Bellefonte Formation and the overlying Loysburg Formation of possible Chazyan age (Kay, 1948, fig. 2). The relationship between these strata will be discussed under "Middle Ordovician Stratigraphy".

MIDDLE ORDOVICIAN STRATIGRAPHY

Unlike the Upper Cambrian and Lower Ordovician strata which consist principally of dolomite, the Middle Ordovician rocks in western Pennsylvania and adjoining areas are composed mainly of limestone. In subsurface these limestones, plus the underlying upper Beekmantown strata, are often lumped together under the name "Trenton limestone". This paper divides

the Middle Ordovician rocks into three units taken from the New York stratigraphic column: the lower unit - the "Black River-Chazy Group" and Pamelia Formation, the middle unit - the Black River Group, and the upper unit - the Trenton Group.

"Black River-Chazy Group" and Pamelia Formation

In Jefferson County, New York (Thousand Islands Region) where the Pamelia was first described, the formation is characterized by its dolomite content, in contrast to the limestones of the overlying Black River and Trenton groups. According to Neuman (1951, p. 305) it consists of green, sandy dolomite grading upward into gray dolomite, and in the upper part dove-colored, dense limestones occur. The maximum thickness of the Pamelia Formation at outcrop is 150 feet.

The position of the Pamelia is one of controversy. Kay (1937, fig. 8) placed the formation in the basal Black River Group, whereas prevailing opinion had previously assigned it to the underlying Chazy. Neuman (1951, p. 304-308) however, on the basis of faunal correlation of New York strata with rocks in southern Pennsylvania and Maryland, inserted the Pamelia between the Black River and Chazy. In the cross-section the stratigraphic interval referred to as Pamelia in New York is considered to be representative of both the Chazy and Black River deposits, and in western Pennsylvania and eastern Ohio this interval is informally designated "Black River-Chazy". It is possible, even plausible, that Chazyan sediments are absent a short distance east of the Findlay Arch, and absent west of the Great Valley of Pennsylvania, and south of Lake Ontario. If such is the case, then the "Black River-Chazy" interval of the cross-section is basal Black River only. In western Pennsylvania and bordering regions the stratigraphic interval of the "Black River-Chazy" will be considered to be of group rank because it is quite likely that it may include several formations. In subsurface in central New York, however, where the interval is called Pamelia, it may perhaps be of formational rank only, because of the relative proximity of outcrops of the Pamelia Formation.

In the Kesselring well in Chemung County, New York, the succession of silty and in part sandy, magnesian limestones, located below the dense limestones of the Black River Group and above the sandy, dolomitic limestones of the Cranesville Formation, has been assigned to the Pamelia Formation. Because of the difficulty in correlating lithologies in the lower part of the Middle Ordovician from well to well, reliance has been placed principally upon gamma-ray characteristics; thus the boundary of the "Black River-Chazy" and Pamelia with the overlying Black River Group as shown on the cross-section is, at best, a division based upon radiation characteristics rather than megascopic lithology. When the Pamelia Formation as defined in the Kesselring well, is traced into western New York and northwestern Pennsylvania, where it is considered as the "Black River-Chazy Group", it becomes a dense, in part argillaceous limestone. In the lower part of the group is a greenish, calcareous siltstone or very siliceous limestone which has been replaced by dense to crystalline limestone in the Power Oil Co. well in West Virginia.

West of the Findlay Arch, strata of Chazyan age are represented by the St. Peter Sandstone Formation; east of the arch, except for local "pockets", the St. Peter is absent, its position in space and time being occupied by carbonates which continue eastward for an unknown distance (Dapples, 1955, p. 450). If Chazyan rocks are present in northwestern Pennsylvania and adjacent areas, it is proposed that they be correlated with the basal 70 feet of what is defined as the "Black River-Chazy Group" in the Shaw well, Warren County, Pennsylvania. This sequence of dense limestones underlain by carbonates of variable dolomitic content appears lithologically similar to the Clover and "Tiger Striped" members of the Loysburg Formation in central Pennsylvania. The Clover is a dark, impure, sublithographic limestone 40 to 80 feet thick lying above a "Tiger Striped" sequence of interbedded limestones and laminated dolomites (Kay, 1944). According to Kay, the "Tiger Striped" varies from a thickness of several hundred feet to "thin transition beds", the difference in thickness is attributed to either a facies relationship with the Bellefonte Formation or to the presence of an erosional unconformity with relief of several hundred feet. Whatever is the relationship between the "Tiger Striped" and the Bellefonte, it is poorly understood.

Overlying the strata questionably designated above as Chazyan in the Shaw well there occurs a greenish, dolomitic siltstone from 8835 to 8860 feet. This siltstone, and also the shales and silty- to sandy carbonates in the same stratigraphic position in the Morse well (in Chautauqua County, New York), may be considered as a western extension of the siliceous limestones of the Hatter Formation in central Pennsylvania. The same interval may also be the eastern correlative of the Glenwood Formation in the Upper Mississippi Valley. Both the Glenwood and Hatter are generally considered to represent the basal formations of the Black River Group. The Hatter Formation in central Pennsylvania consists of dense to granular, and in part shaly, limestones overlain by siliceous and argillaceous limestone or calcareous siltstone (Kay, 1944). The Glenwood Formation in subsurface in southern Michigan, northeastern Indiana, and Ohio is composed of green, brown or gray sandy shale which is sometimes pyritic (Cohee, 1945a). In Ohio, it is worth noting, the silty and sandy section directly above the datum unconformity has been called "Glenwood" (Shearrow, 1959b); in this paper that section is regarded as part of the Bellefonte Formation.

Trenton-Black River Groups

According to Kay (1937), the Black River Group comprises three formations - the lower Pamelia, the middle Lowville, and the upper Chaumont. In the cross-section, as previously mentioned, the Pamelia is given a different stratigraphic position and is not included within the Black River Group; thus the author's group is believed to represent approximately the upper two formations of Kay's group. The Lowville Formation at outcrops in New York is a sublithographic, dove-colored limestone 50 to 60 feet thick, and the overlying Chaumont, 25 feet thick, is a dark-colored, semicrystalline limestone containing black chert in its lower part (Swartz, 1948). In subsurface, as observed in the wells of the cross-section, the Black River group is a medium- to dark-colored, dense lithographic lime-

stone; the lower part in New York containing occasional interbeds of magnesian and dolomitic limestone.

The Trenton Group in New York consists of six formations (Kay, 1937) which, in ascending order are: Rockland (60 feet), Kirkfield (100 feet), Sherman Fall (200 feet), Cobourg (170 feet), Collingwood (75 feet), and Gloucester (75 feet); the first four are limestones and the last two are shales. According to Kay (1937) the Rockland Formation is a dark, medium- to fine-textured limestone with shaly partings, and the Kirkfield consists of sugary, fossiliferous limestone. The Sherman Fall is more shaly than its enclosing formations, and the overlying Cobourg Formation is a medium- to coarse-textured limestone almost lacking in shale beds and partings. Metabentonites are found scattered throughout the interval from and including the Rockland Formation into the lower half of the Sherman Fall Formation. The Collingwood Formation is composed of alternating beds of shale and limestone, and the Gloucester Formation is a grayish-black shale.

In Ohio (Shearrow, 1957) and Michigan (Cohee, 1948) subsurface sections, the division between the Trenton and Black River groups is placed at the contact of the dense to lithographic limestones with the argillaceous, fossiliferous, very fine- to fine-textured limestones. The writer of this paper subscribes to this distinction. Near the base of the Trenton in Ohio and northwestern Pennsylvania metabentonites often occur. In northwestern Pennsylvania and in parts of Michigan (Cohee, 1948) the basal Trenton is more argillaceous or more shaly than the limestones immediately adjacent, and in some wells traces of dark chert are found near the Trenton-Black River contact. The chert suggests possible correlation with the Chaumont Formation.

The metabentonites that occur in the Middle Ordovician limestones appear to be of limited use for correlation purposes. Although they are present throughout most of the northern Appalachian Basin, they may be completely or in part absent in local sections, (as in the Morse well and in the Black River of the Shaw well), possibly because of the presence of an unconformity, but more likely because of gradation into other lithologies. Whatever the cause of their absence, it is hazardous to employ metabentonites in regional correlation.

The limestones of the Trenton Group in northwestern Pennsylvania and adjacent area grade upward into the Utica Formation, a grayish-black, calcareous shale which is represented by the Collingwood and Gloucester formations at outcrops in New York. The top of the Utica Formation in this report is taken to be the top of the very dark-colored shales and this point usually coincides with the first appearance of siltiness above the Trenton limestones. The Utica is absent in the Morse and Wilson wells in New York and the limestones of the Trenton are overlain by dark gray shales with interbeds of siltstone. Concomitant with the absence of the Utica is a thickening of the limestones. For this reason the writer believes the Utica to be in facies relationship with the limestones of the Trenton.

In the Mohawk Valley, New York, eastward across the Adirondack Arch the limestones of the Sherman Fall Formation grade laterally into the dark

shales of the Canajoharie Formation; the overlying Cobourg, in somewhat similar manner is replaced by the Utica Formation on the eastern side of the arch (Kay, 1937). The Lobdell well, in Chenango County, New York, is believed by the writer to be east of, and very close to, the axis of the Adirondack Arch. Most of the Trenton Group is represented by shale which on the cross-section has been called Utica, but may be in part the Canajoharie Formation.

It is suspected that the Utica shale-Trenton limestone facies relationship continues westward from western Pennsylvania into Ohio. Across the northern part of Ohio the interval from the top of the very dark shales of the Cincinnatian to the base of the Trenton limestone remains relatively constant in thickness, varying from 410 to 450 feet. The thickness of the lithologies, however, varies with respect to one another and where the shale is thick, the limestone is thin, and vice-versa.

RESUME OF CAMBRO-ORDOVICIAN STRATIGRAPHY

Assuming a Precambrian age for the rocks underlying the Upper Cambrian sandstones, the Jacobsville, Mount Simon, and Potsdam formations are the deposits of the initial Paleozoic seas which spread over the region from the Upper Mississippi Valley to New York and northwestern Pennsylvania. Deposition was essentially continuous from Late Cambrian into Early Ordovician time, although minor hiatuses undoubtedly did occur. In the Upper Mississippi Valley a break in sedimentation has been postulated at the top of the Galesville Formation (Twenhofel et al, 1935), and in eastern Pennsylvania faunal evidence indicates that the Franconian Stage is missing (Wilson, 1952). Some persons (Twenhofel et al, 1935; Shearrow, 1959a, p 4; Ulrich and Cushing, 1910) place an unconformity of considerable magnitude at the Cambro-Ordovician boundary, but for reasons already stated the writer believes the time gap, if and where it is present, to be of minor significance.

During most of the Paleozoic Era, lands to the south and east of the Appalachian miogeosyncline supplied the detrital sediments to that trough and its northwestern shelf region. During Late Cambrian, and at least some of Early Ordovician time, however, there was a change in the provenance of the detrital material being fed into the basinal area; the source of the sediments was from the north and northwest, probably from the Canadian Shield and the Wisconsin Dome. Little, if any, detrital material was derived from the southeast; perhaps, as Woodward (1957) suggests, the geosyncline was open to the Atlantic Ocean. The increase of sand in the direction of source is shown by the Eau Claire Formation as it is traced from Ohio and western Pennsylvania into the Northern Peninsula of Michigan and by the Little Falls Formation as it is followed westward through New York. The relatively small amount of sandstone above the Potsdam Formation in the Lobdell well, New York, may indicate that the Adirondacks were not a positive element following deposition of that formation and possibly were not affective as a source area until Middle Ordovician time.

Beekmantown strata in the area of the cross-section underwent at least two uplifts during Early Ordovician time. The first occurred following Lower Beekmantown deposition and permitted erosion of all of the Lower Canadian and some of the Upper Cambrian strata in northeastern Ohio, northwestern Pennsylvania, and western New York. The seas were restricted from this area until Late Canadian time when marine incursions of short duration laid down the upper Beekmantown rocks. Meanwhile in central Pennsylvania more or less continuous deposition was taking place. Epeirogenic uplift at the end of Early Ordovician time prevented the seas from again invading the area of northwestern Pennsylvania and surrounding region until the time of deposition of the "Black River-Chazy Group".

Until more general agreement is reached on the stratigraphy of the outcrops of the Chazyan sediments, it is fruitless to draw any conclusion concerning the distribution of these rocks.

One of the greatest inundations of the Cambrian and Ordovician periods occurred during the time of deposition of the Black River Group when lime muds were deposited from New York and Pennsylvania westward to the Upper Mississippi Valley. There was orogenic activity east of New York beginning in Late Mohawkian time, and dark clays and muds were deposited in the region east of the Adirondack Arch. These clastic sediments gradually spread westward across the arch, and by the end of the Middle Ordovician epoch the shales of the Utica Formation had replaced the limestones of Trenton Group throughout most of the northern Appalachian Basin.

OIL AND GAS CONSIDERATIONS IN PENNSYLVANIA

To date (October 1959), there are in Pennsylvania sixteen wells that have been drilled to or through the "Trenton limestone"; of these sixteen wells, eleven bottom in Cambrian strata and only one goes into "Precambrian basement". Based on this meager evidence conclusions regarding oil and gas possibilities in the lower part of the Paleozoic section would be largely flights of fancy. Much of what is written below is but a recapitulation of ideas previously expressed by other authors.

Trenton, Black River and Upper "Black River-Chazy" Limestones

It appears that the optimum conditions for the accumulation of oil in the "Trenton limestones" is partial dolomitization (interbedded limestones and dolomites) over a structurally high area; such is the geologic situation that has resulted in the production of oil in northwestern Ohio along the Findlay and Kankakee arches (Cohee 1945b). In southern Michigan oil has recently been found in fractured? dolomites (World Oil, Oct. 1959; Oil and Gas Journal, Feb. 2, 1959). Thus far, the Trenton dolomite occurrences in Pennsylvania have been restricted to the upper 10 to 15 feet of Trenton limestone in western Erie County. The Jay Childs well, located in the northwestern part of that county, produced one barrel of oil per day from the dolomite. Elsewhere in the state, the "Trenton" has yielded gas showings in limestones containing subordinate shale beds and partings.

In New York, east and southeast of Lake Ontario, gas production in the "Trenton" has been obtained from shale partings, shale beds, and from joints and cavities within the limestone (Hartnagel, 1938, p. 97).

Lower "Black River-Chazy" and Upper Beekmantown Strata

This sequence of clastic and non-clastic rocks may be one of the better sources of oil and gas within the Cambro-Ordovician strata. Showings of gas have been frequently reported from wells which have tested this part of the section. The diverse lithology permitting the juxtaposition of possible source and reservoir beds in combination with the presence of unconformities both below and within the succession of strata enhances the possibilities of obtaining commercial production from this interval.

Upper Cambrian Dolomites and Sandstones

The dolomites and sandstones immediately underlying the unconformity used as a datum plane in the cross-section have also offered encouragement in the search for oil and gas. According to Shearrow (1959a) oil production in Seneca and Marion counties in northwestern Ohio, and in Licking County in central Ohio was obtained from "the erosional zone at the top of the Trempealeau rocks, beneath the Glenwood shale". In western Pennsylvania these rocks have yielded only salt water and showings of gas, but the number of wells and the area tested is small. It is worth noting that similar lithologies (Arbuckle and Ellenburger) under similar geologic conditions have produced oil and gas in the Mid-Continent region.

Because the knowledge of the subsurface stratigraphy of the Cambro-Ordovician strata in western Pennsylvania and adjacent areas is so little understood and for that reason subject to so many stratigraphic interpretations, and because of the limited purpose of this investigation, it seems premature and imprudent to attempt at this time any further evaluation of the oil and gas possiblities in the Cambro-Ordovician section.

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